Phosphorus Removal: The Impact Upon Water Quality in the Bow River Downstream of Calgary, Alberta

Bow River Data Base 1980 - 1985

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Pollution Control Division
Water Quality Control Branch

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PHOSPHORUS REMOVAL:
THE IMPACT UPON WATER QUALITY IN THE BOW RIVER
DOWNSTREAM OF CALGARY, ALBERTA
BOW RIVER DATA BASE 1980 - 1985

prepared by:

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WATER QUALITY CONTROL BRANCH

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ENVIRONMENTAL PROTECTION SERVICES

ALBERTA ENVIRONMENT

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EXECUTIVE SUMMARY

Alberta Environment, Water Quality Control Branch, conducted a limnological study of the Bow River in conjunction with the South Saskatchewan River Basin Study. Data collected from 1980 to 1982 defined the temporal characteristics of water quality and the primary producers downstream of Calgary. Advanced phosphorus removal was fully operational at Calgary Sewage Treatment Plants by the winter of 1982. Sample collection from 1983 to 1985 monitored the effect of phosphorus reduction on the river water quality. The objective of this report is to compare these data, with emphasis on nutrient concentrations and primary producer standing crops.

Dissolved phosphorus concentrations have been substantially reduced at both the Fish Creek and Bonnybrook Sewage Treatment Plants. Accordingly, sites downstream of the effluents have reflected this decrease. However, nitrate-nitrite nitrogen concentrations and bacteriological counts have not been noticeably affected since phosphorus removal was implemented.

Epilithic algal standing crops have not decreased in response to the lowered dissolved phosphorus concentrations. This may be attributed to their ability to accumulate phosphorus to facilitate growth when nutrients are limited. Another factor may be their ability to take up nutrients from their substrate, where phosphorus may still be readily available.

The macrophyte standing crop did not immediately decrease once dissolved phosphorus concentrations were reduced. In 1985, however, the peak macrophyte biomass was less than in previous years. The delayed response may have been due to the ability of macrophytes to take up phosphorus from the substrate and store it in rhizomes until the next growing season. If such was the case, reductions in the 1985 macrophyte community may reflect the depletion of the nutrient stored (nutrient sink) in the substrate. One would then expect to see a further decrease in the macrophyte population in the coming years if the nutrient sink is gradually reduced by physical, chemical and biotic factors.

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1.0 INTRODUCTION

Alberta Environment, Water Quality Control Branch, was instrumental in defining the temporal characteristics of water quality and the primary producers of the Bow River, 1980 through 1982.

Quantitative studies were presented by Cross, Hamilton, Charlton 1986; Charlton, Hamilton, Cross 1986; and Charlton 1986. Nutrients such as phosphorus were highly correlated with the standing crops of algae and macrophytes. However, the Bow and Oldman Rivers generally supported higher nutrient concentrations and higher primary producer standing crops in their middle reaches.

In the Bow River, macrophytes interfere with agricultural and recreational use of water immediately downstream of the Bonnybrook Sewage Treatment Plant. The nuisance growth of plants also impedes the hydrologic regime, affecting variables such as river temperature and dissolved oxygen.

The installation of the phosphorus removal system was completed on September 21, 1982 at the Fish Creek Sewage Treatment Plant and on December 2, 1982 at the Bonnybrook Sewage Treatment Facility. The facilities became fully operational during the winter of 1982-83. A total of 117 million dollars was spent to upgrade the two plants, thirty-two million of which were allotted to the installation of phosphorus removal facilities.

The alum precipitation method of phosphorus removal has proven to be a very effective technique. Process alum concentrations of 80 $mg \cdot L^{-1}$ have reduced effluent phosphorus from 3.65 $mg \cdot L^{-1}$ total phosphorus in Bonnybrook effluent in 1981 to an average of 0.7 $mg \cdot L^{-1}$ total phosphorus in 1985. Currently, effluent phosphorus concentrations from both the Bonnybrook and Fish Creek Sewage Treatment Plants are less than 1.0 $mg \cdot L^{-1}$, in accordance with the License to Operate issued by Alberta Environment.

The following report will present Alberta Environment's findings with respect to the trends or changes that have occurred in Bow River water quality during the past five years. Specific reference is made to the means and ranges of nutrient concentrations, particularly dissolved phosphorus and nitrate-nitrite nitrogen. The temporal changes of nutrients, epilithic and planktonic algal standing crops, river discharge and macrophyte standing crops are also presented.

2.0 METHODS AND MATERIALS

Charlton, et al. 1986 and Cross, et al. 1986 presented in detail the field and laboratory methods employed during 1980 through 1982. Since that time the sampling frequency and detailed studies have been modified to discern the impact of phosphorus removal upon Bow River water quality. Actual field and laboratory techniques were altered slightly and are presented.

2.1 Frequency of Sampling

During 1983 and 1984 the six mainstream sites on the Bow River, Sites 1, 2, 5, 6, 13 and 7 (Fig. 1), were sampled twice per month, spring through fall. In 1985 samples were collected every three weeks. Winter samples were collected three times in 1983 - 1984 and monthly during 1984 - 1985. A new site located near Cluny was selected in the spring of 1985 because of restricted access to Site 6 (Bassano Dam).

Between Calgary and Carseland, thirteen sites (referred to as M1 through M13) were sampled five times from May to September of 1984 to supplement data previously collected. The locations of these sites are also presented in Figure 1. Table 1 presents a list of the sampling locations and their respective NAQUADAT station codes.

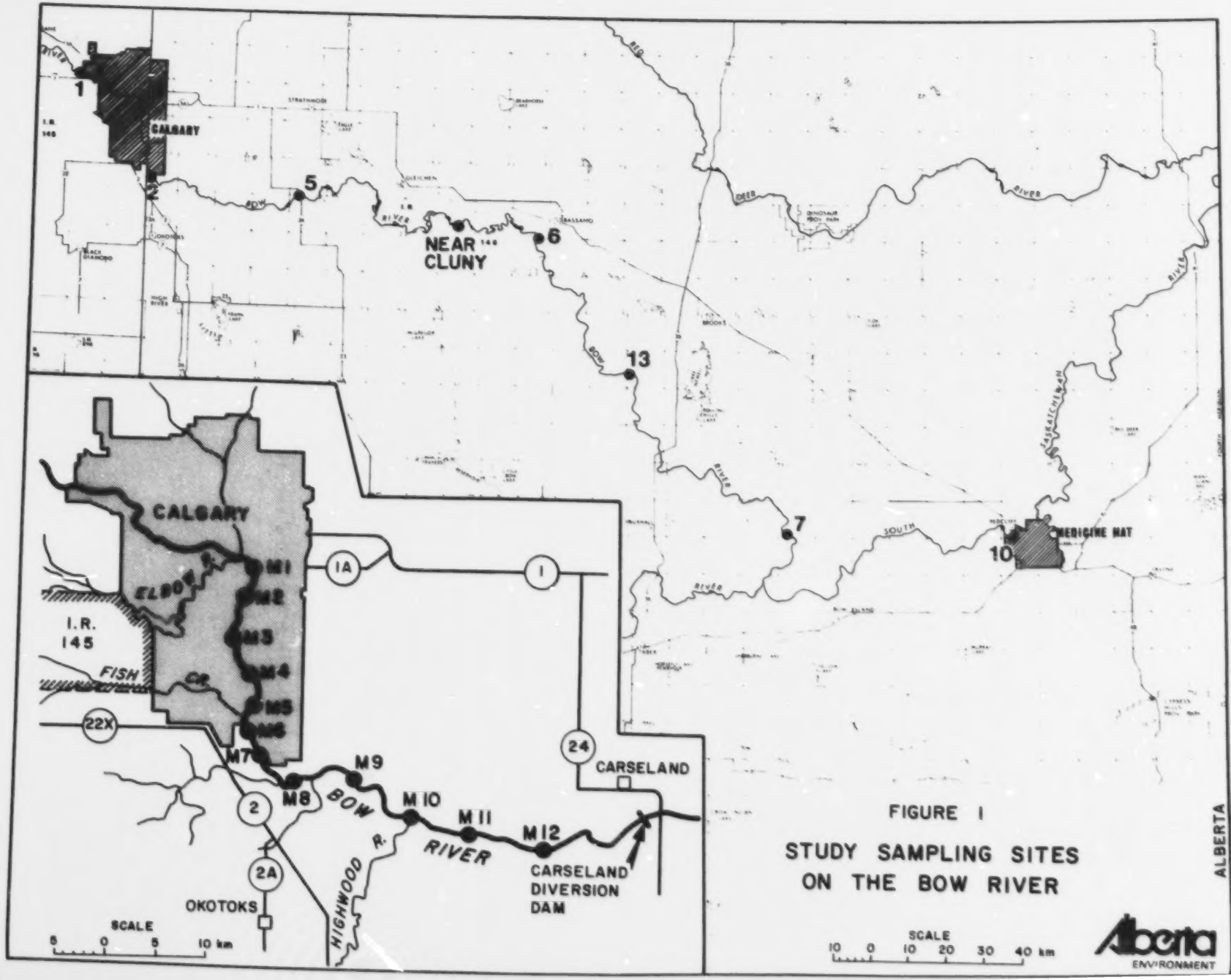

FIGURE 1

STUDY SAMPLING SITES ON THE BOW RIVER

TABLE 1 Bow River sampling site names and their respective NAQUADAT station codes.

DESCRIPTION	NAQUADAT CODE
Bow River at 85 St. Bridge - Site 1	00AT05BH2105
M1	00AT05BH2200
M2	00AT05BH2210
M3	00AT05BH2220
M4	00AT05BH2230
M5	00AT05BH2240
M6	00AT05BM2159
M7	00AT05BM2165
Bow River at Stiers Ranch - Site 2 (M8)	00AT05BM2160
M9	00AT05BM2170
M10	00AT05BM2175
M11	00AT05BM2182
M12	00AT05BM2185
M13	00AT05BM2224
Bow River at Carseland - Site 5	00AT05BM2215
Bow River at Cluny	00AT05BM2230
Bow River below Bassano Dam - Site 6	00AT05BM2240
Bow River at Bow City - Site 13	00AT05BN2245
Bow River at Ronalane Bridge - Site 7	00AT05BN2270

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2.2 Water Quality Variables

Table 2 presents a list of the water quality and related variables which were monitored at the six mainstream Bow River sites during 1983 and 1984. Specific analyses and collection techniques are described by the Alberta Environment NAQUADAT dictionary.

Chemical analyses were performed by Chemex Labs of Calgary after spring 1984 because the services previously provided by Environment Canada were relocated to Saskatoon, Saskatchewan.

2.3 Nutrients

Subsurface (0.30 m depth) samples were collected in actively flowing river sites. The river midstream was utilized whenever possible. Water samples for chemical analysis were field filtered and/or preserved on site, stored at 4°C and transported to Chemex Labs, Calgary within 24 hours of collection. Sartorius membrane filters (0.45 µm), used for filtration of dissolved nutrient fractions, were replaced with Nucleopore (0.45 µm) filters in 1984. Dissolved phosphorus and nitrogen duplicates were tested by Alberta Environment and the Alberta Environmental Centre at Vegreville, Alberta to ensure that the two filters yielded similar results.

TABLE 2 Water quality and related variables and their respective NAQUADAT codes for the 1983 and 1984 Bow River monitoring program.

VARIABLE	NAQUADAT CODE
Total phosphorus	15406L
Total dissolved phosphorus	15103L03F
Nitrate-nitrite nitrogen	07110L10F
Total ammonia nitrogen	07506L05L
Total alkalinity	10122F
Chlorophyll a - phytoplankton	06720L
Chlorophyll a - epilithic	06721L
Total coliforms	36001L
Faecal coliforms	36011L
Dissolved oxygen	08102F
Specific conductance	02041F
pH	10301F
Water temperature	02061F

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2.4 Chlorophyll *a*

Whole water samples were filtered through glass fibre (Whatman GF/C) filters in order to collect the suspended (planktonic) chlorophyll *a*. Filters were then covered with anhydrous magnesium carbonate, wrapped in foil and stored at -4°C until shipped to Alberta Environment, Edmonton for analysis.

Epilithic chlorophyll *a* was acquired by randomly collecting nine to twelve rocks in continuous flow areas. Using a plastic template, duplicate 4 cm^2 areas were delineated on each rock. The epilithic material within these areas was removed using a sharp scalpel and placed onto Whatman GF/C filters with anhydrous magnesium carbonate. Epilithic chlorophyll *a* filters were also wrapped in foil and stored at -4°C until shipped to Alberta Environment, Edmonton for analysis.

Pigments of both the epilithic and planktonic communities were extracted into 90% acetone. Epilithic samples were homogenized using a Polytron PCU-2-110 homogenizer to ensure complete extraction. The spectrophotometric method and equations of Moss (1967a, 1967b) were used to estimate the quantity of chlorophyll *a* present. Corrections were made for phaeophytin. Chlorophyll *a* analysis was performed as soon as possible following sample collection, usually within two weeks time.

2.5 Macrophyte Standing Crops

Macrophytes were collected at Sites M3R (right bank), M4R and M6L (left bank) every two weeks, June through September, of 1983 and 1985. During 1984, macrophyte sampling commenced in May. "Peak biomass" was measured at all thirteen sites, M1 through M13, in late August or early September of all three years. The methods employed did not vary from those presented in Charlton, et al. 1986.

2.6 Physical Variables

Physical variables, i.e., dissolved oxygen, temperature, specific conductance and pH, were measured using a Hydrolab Digital Meter, Model 4041, beginning in 1983. Dissolved oxygen was also regularly determined at all sites using the Winkler method.

3.0 RESULTS

The limnological characteristics of the Bow River, 1980 through 1985, are presented below.

3.1 General Biotic and Abiotic Characteristics

Table 3 presents the mean and range of values for three exemplary sites upstream (Site 1) and downstream of Calgary (Sites 2, and 5). Sites 1, 2, and 5 will be discussed in detail. Data for the remaining mainstream sites, 6 near Cluny, 13 and 7 are presented in Appendix I.

Dissolved phosphorus concentrations at Site 1 upstream of Calgary averaged 0.004 $mg \cdot L^{-1}$ prior to 1983 and 0.006 $mg \cdot L^{-1}$ after 1983. These values, although higher in more recent years, are lower than the mean values reported for any other downstream site. Conversely, Site 2 downstream of Calgary underwent a reduction in dissolved phosphorus concentration after 1982. At Site 2, it decreased from a mean of 0.169 $mg \cdot L^{-1}$ (1980 - 1982) to 0.022 $mg \cdot L^{-1}$ (1983 - 1985). At Site 5, dissolved phosphorus was higher prior to 1983 than afterward. The ambient concentration averaged the same after 1983 at Site 5, as that found at Site 2 after 1983.

TABLE 3 The mean and range of dissolved phosphorus, nitrate nitrite nitrogen, phytoplankton and epilithon for the Bow River Sites 1, 2 and 5 (1980 to 1985 inclusive).

Site 1	DISSOLVED PHOSPHORUS $mg \cdot L^{-1}$ $\bar{x}$	Range	NITRATE/NITRITE NITROGEN $mg \cdot L^{-1}$ $\bar{x}$	Range	PHYTOPLANKTON CHLOROPHYLL a $mg \cdot m^{-3}$ $\bar{x}$	Range	EPILITHON CHLOROPHYLL a $mg \cdot m^{-2}$ $\bar{x}$	Range
1980	.003*	L.003 to .009	.041*	L.01 to.16	4.15	.50 to 11.5	36.39	11.0 to 72.0
1981	.007*	L.003 to .023	.052*	L.01 to .11	2.99	.40 to 8.6	24.14	8.0 to 50.2
1982	.003*	L.003 to .004	.070	.03 to .12				
x	.004*	L.003 to .023	.054*	L.01 to .16	3.57	.40 to 11.5	30.52	8.0 to 72.0
1983	.008*	L.003 to .037	.032	.01 to .08	1.47	.15 to 2.90	78.55	14.2 to 168.9
1984	.007*	L.003 to .040	.026*	L.01 to .10	1.48	.00 to 4.38	48.96	8.7 to 123.3
1985	.004*	L.003 to .006	.024	L.01 to .06	1.57	.40 to 3.94	40.80	.00 to 83.57
x	.006*	L.003 to .040	.027*	L.01 to .10	1.51	.00 to 4.38	56.10	.00 to 168.9

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TABLE 3 The mean and range of dissolved phosphorus, nitrate nitrite nitrogen, phytoplankton and epilithon for the Bow River Sites 1, 2 and 5 (1980 to 1985 inclusive) (cont'd).

Site 2	DISSOLVED PHOSPHORUS $mg \cdot L^{-1}$		NITRATE/NITRITE NITROGEN $mg \cdot L^{-1}$		PHYTOPLANKTON CHLOROPHYLL a $mg \cdot m^{-3}$		EPILITHON CHLOROPHYLL a $mg \cdot m^{-2}$	
	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range
1980	.194	.038 to .370	.769	.28 to 1.4	3.19	.93 to 9.85	269.36	122.8 to 438.7
1981	.164	.019 to .330	1.005	.17 to 2.4	8.02		229.53	11.8 to 488.5
1982	.150	.140 to .160	1.800	1.40 to 2.1				
x	.169	.019 to .370	1.191	.17 to 2.4	5.61	.93 to 9.85	249.44	11.8 to 488.5
1983	.026	.010 to .064	.731	.31 to 1.3	6.84	2.45 to 11.64	289.98	14.8 to 678.7
1984	.020*	L.003 to .070	.863	.38 to 1.4	5.12	1.64 to 12.92	244.18	53.1 to 701.8
1985	.021	.014 to .030	1.158	.58 to 1.8	5.16	1.39 to 13.61	190.78	39.3 to 441.3
x	.022*	L.003 to .070	.917	.31 to 1.8	5.71	1.39 to 13.61	241.65	14.8 to 701.8

TABLE 3 The mean and range of dissolved phosphorus, nitrate nitrite nitrogen, phytoplankton and epilithon for the Bow River Sites 1, 2 and 5 (1980 to 1985 inclusive) (cont'd).

Site 5	DISSOLVED PHOSPHORUS $mg \cdot L^{-1}$ $\underline{x}$	Range	NITRATE/NITRITE NITROGEN $mg \cdot L^{-1}$ $\underline{x}$	Range	PHYTOPLANKTON CHLOROPHYLL a $mg \cdot m^{-3}$ $\underline{x}$	Range	EPILITHON CHLOROPHYLL a $mg \cdot m^{-2}$ $\underline{x}$	Range
1980	.142	.033 to .250	.780	.26 to 1.2	5.53	2.4 to 8.5	329.65	189.8 to 739.4
1981	.138	.030 to .290	.828	.28 to 1.5	7.04	1.7 to 18.03	211.85	63.0 to 525.9
1982	.160	.100 to .220	.840	.49 to 1.2				
x	.147	.030 to .290	.816	.26 to 1.5	6.29	1.7 to 18.03	270.75	63.0 to 739.4
1983	.020	.005 to .050	.828	.37 to 1.2	5.03	2.5 to 9.61	236.83	11.3 to 743.4
1984	.025*	L.003 to .083	.932	.07 to 1.5	6.36	.5 to 19.82	352.23	97.6 to 752.8
1985	.021	.015 to .029	1.020	.70 to 1.5	5.99	1.9 to 11.4	256.23	135.7 to 382.3
x	.022*	L.003 to .083	.927	.07 to 1.5	5.79	.5 to 19.82	281.76	11.3 to 752.8

L = Less than the detection limit
* = Means include values at the detection limit
x = Mean

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At the remaining downstream sites (6, 13 and 7), dissolved phosphorus concentrations were lower after 1982 and decreased at each successive location. Dissolved phosphorus concentrations in the middle and lower reaches of the Bow River were, on average, lower after the installation of phosphorus removal at Calgary than previously recorded values (Appendix I).

Nitrate-nitrite nitrogen concentrations were also lower upstream of Calgary than any other sampling site on the Bow River. At Site 1, it averaged 0.054 $mg \cdot L^{-1}$ between 1980 and 1982, and 0.027 $mg \cdot L^{-1}$ after 1982. Nitrate-nitrite concentrations were generally highest at Site 2, averaging 1.191 $mg \cdot L^{-1}$ before 1983 and 0.917 $mg \cdot L^{-1}$ after decreasing at each successive downstream site.

Phytoplanktonic standing crops were also generally lower upstream of Calgary than in the middle reaches of the Bow River. However, standing crops at Site 1 were higher during 1980-82 than during 1983-85. A similar pattern was detected for all other Bow River sites (Appendix I).

Epilithic algal standing crops were similar at Site 1 and Site 7. The quantity of chlorophyll a was higher after 1983 than prior to 1983 at both sites. The highest epilithic algal standing crops were detected at Site 5 followed by Site 2. However, little difference was found between mean standing crops before and after the installation of phosphorus removal (Table 3).

3.2 Temporal Patterns in the Bow River

The temporal changes of dissolved phosphorus, nitrate-nitrite nitrogen, phytoplanktonic and epilithic standing crops are presented for Site 2 for 1984 through 1985 in Figure 2.

Prior to 1983, dissolved phosphorus peaked during each winter, i.e., December - January. Conversely, dissolved phosphorus concentrations decreased to annual minima during June when the spring spate exerted a diluting effect.

After 1983, dissolved phosphorus concentrations were much lower and fluctuated irregularly. Peak values were detected in the spring (April) of 1983 and 1984 and September 1984. Little seasonal variation of dissolved phosphorus was detected at Site 2 throughout 1985.

Nitrate-nitrite nitrogen concentrations decreased during the spring spates of all years (1980 - 1985). Peak concentrations were found during September 1980 and January 1982. After 1983, nitrate-nitrogen concentrations fluctuated more radically and exhibited a very regular pattern. Peaks consistently occurred during October and May of each year, 1983 through 1985. Minima were found each year during February and June/July.

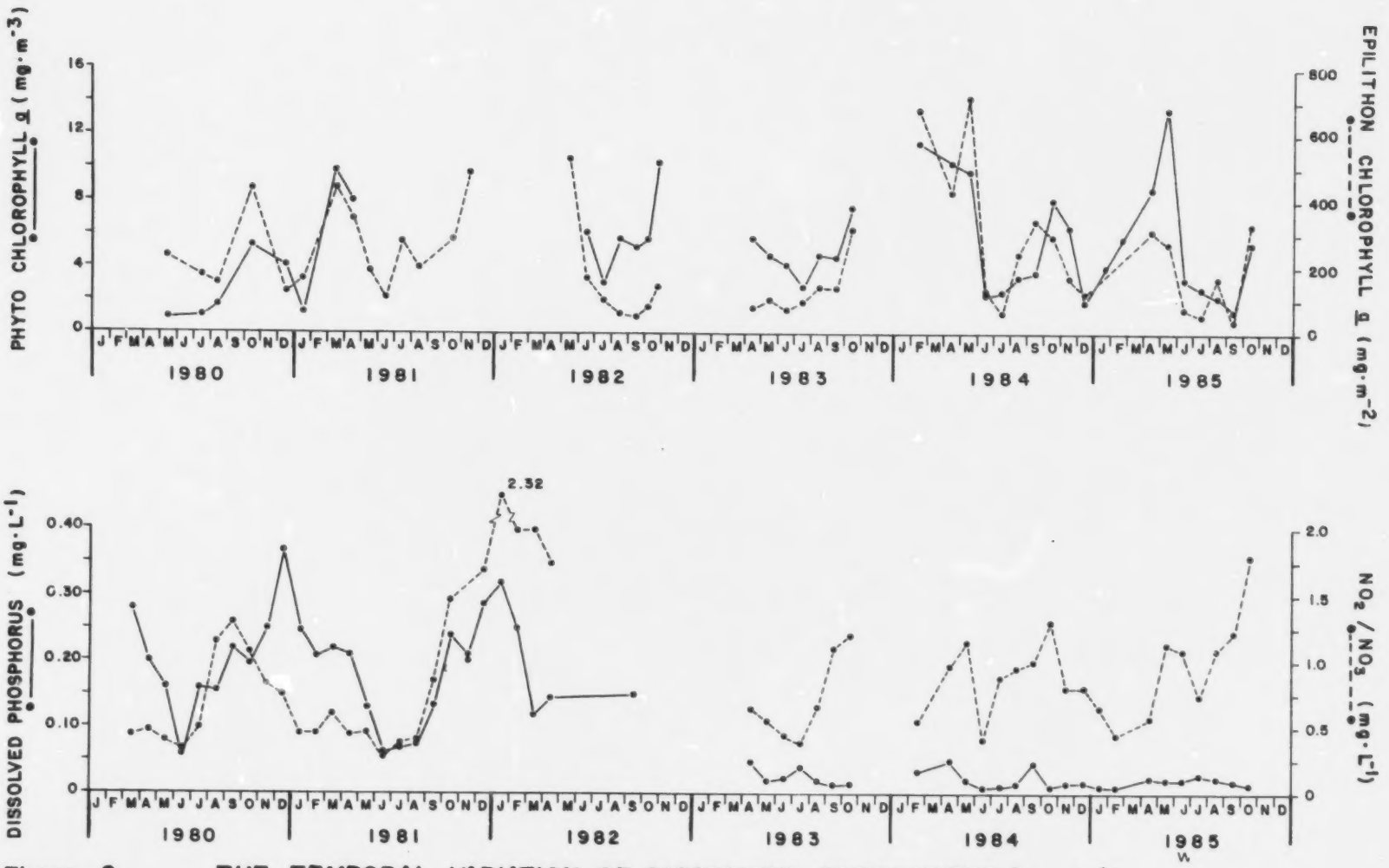

Figure 2 THE TEMPORAL VARIATION OF DISSOLVED PHOSPHORUS ($mg \cdot L^{-1}$), NITRATE-NITRITE NITROGEN ($mg \cdot L^{-1}$), PHYTOPLANKTON (mg CHLOROPHYLL $a \cdot m^{-3}$) AND EPILITHON (mg CHLOROPHYLL

Epilithic chlorophyll a underwent frequent, regular, seasonal fluctuations. It appeared that epilithic chlorophyll a peaked during the fall (September to October) and spring (March to May). One exception was detected in early February of 1984. Minimum epilithic standing crops frequently occurred during December when slush ice is particularly abrasive upon the benthic community. Minima also occurred during the spring spate, which is similarly abrasive because of high stream velocities.

Phytoplanktonic and epilithic algal standing crops did not appear to decrease following the installation of phosphorus removal at Calgary. In contrast with dissolved phosphorus and nitrate-nitrite nitrogen, these communities were, on average, higher during 1983 through 1985 (Figure 2, Table 3).

3.3 Faecal and Total Coliform Bacteria

Faecal and total coliform bacteria were compared at each of the six mainstream sites on the Bow River during 1984 and 1985. Figure 3 presents the mean (geometric) numbers found.

The highest total and faecal coliform numbers were found at Site 2 located 23 km downstream of Calgary. Higher numbers are likely to occur closer to outputs of treated sewage effluent, however, those areas were not routinely monitored.

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g:\m-JAI SITE 2, 1980-1985

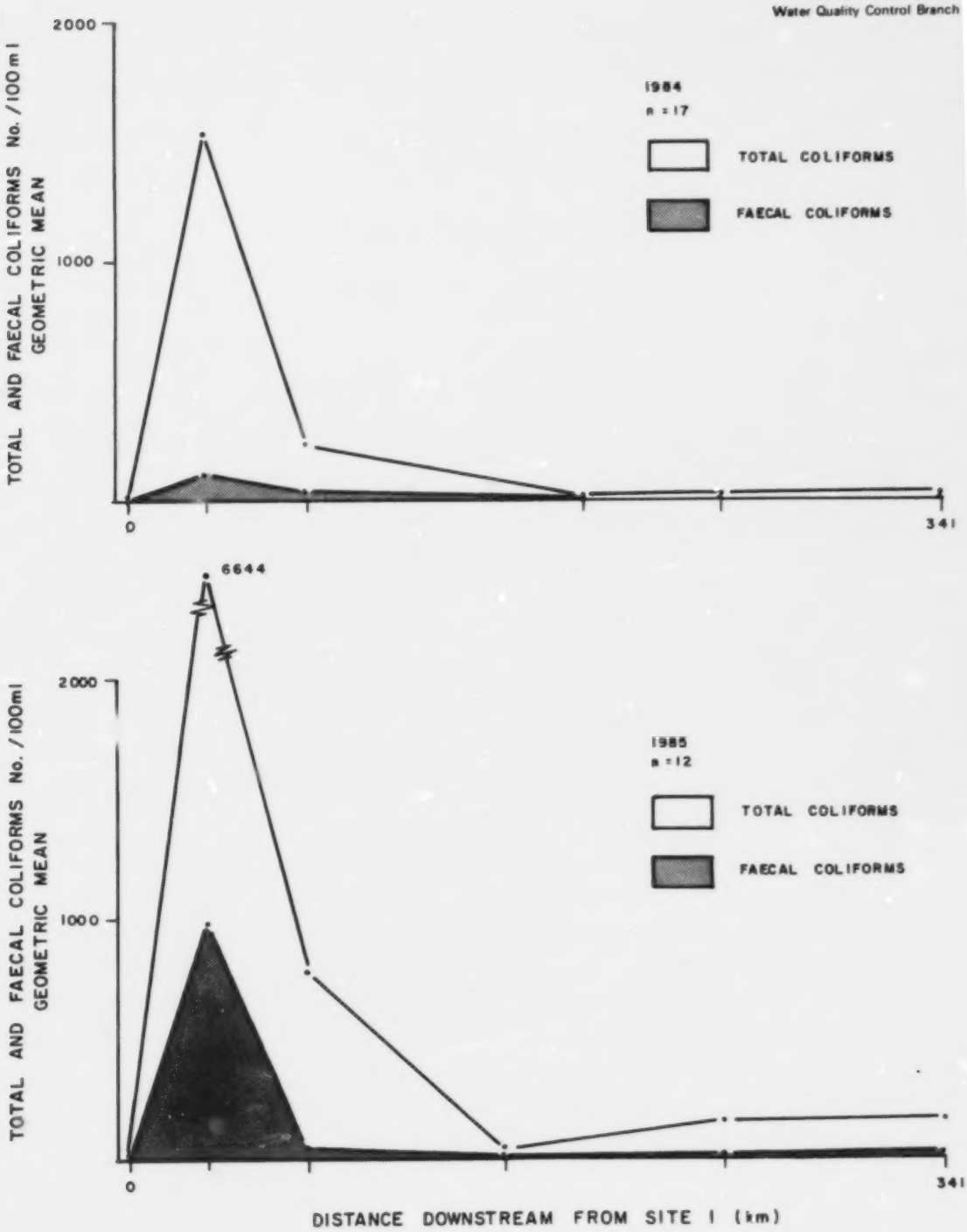

Figure 3 GEOMETRIC MEAN (1984, 1985) OF TOTAL AND FAECAL COLIFORMS (No. / 100ml) AT SIX MAINSTREAM SITES ON THE BOW RIVER

Bacterial numbers were higher during 1985 than 1984 at all Bow River mainstream sites. Numbers dramatically increased downstream from Site 1 (Bowness), peaked at Site 2 (Stiers Ranch), then gradually decreased at Site 5 (Carseland) and Site 6 (Bassano Dam/Cluny). Mean bacterial counts were similarly low at Site 6, Site 13 and Site 7. During 1985, total coliform numbers at Sites 13 and 7 were higher than those detected at Site 6 near Cluny. Average total coliform counts at Site 2 (n = 12) exceeded the recommended Alberta Surface Water Quality Objective of 5000/100 ml throughout 1985.

3.4 Temporal Changes in Bow River Discharge

Figure 4 presents the mean weekly discharges for the Bow River during the open water seasons for 1980 through 1985. Also shown are the maximum weekly discharges for this period.

The six years of the study covered a period of quite variable discharge rates. From 1980 to 1982, discharges were relatively high. The highest mean discharge approached or exceeded 300 $m^3 \cdot s^{-1}$ each year. By contrast, during 1983 to 1985 discharges were low with the high mean discharges not exceeding 200 $m^3 \cdot s^{-1}$ each year. Thus, the river discharge and the amplitude of the spring spate were much lower after 1982.

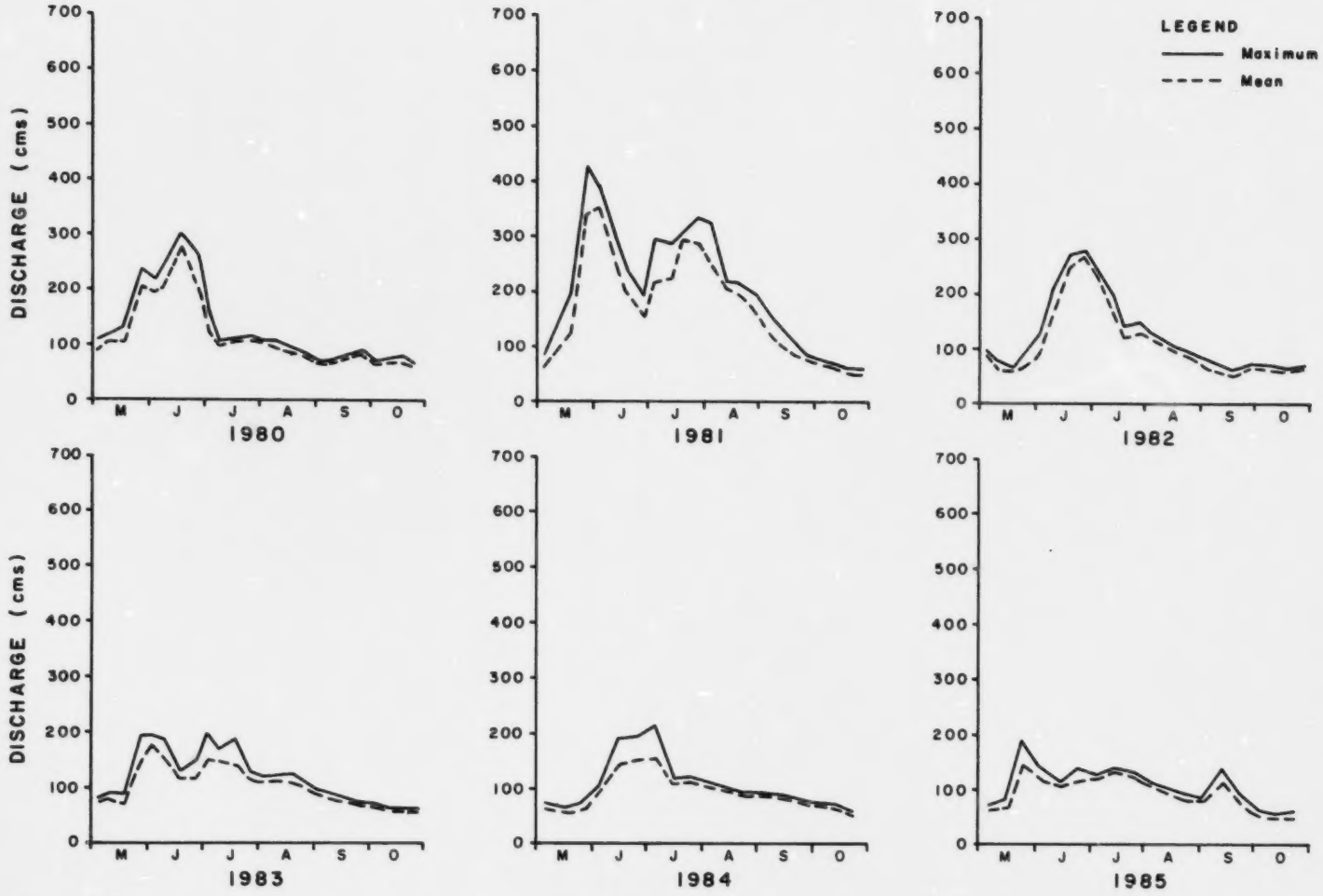

Figure 4 DISCHARGE IN THE BOW RIVER AT CALGARY (1980-85)

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The pattern of high and low river discharges between 1980 and 1985, while more sustained during the study period, is consistent with the historical pattern of the Bow River. During the period 1970 to 1979, river flows fluctuated from year to year (Hamilton and North 1986). It is anticipated that the low flows evident in the latter half of the study will not be sustained and more normal flows will occur in future years.

3.5 Temporal Fluctuations of Dissolved Phosphorus Downstream of Calgary

Figure 5 presents the temporal variation of dissolved phosphorus at five selected river locations in the vicinity of Calgary. Site M1R (upstream of the Bonnybrook Sewage Treatment Plant) continually had very low dissolved phosphorus concentrations, i.e., less than 0.01 $mg \cdot L^{-1}$. Little difference was apparent among the years 1981, 1982 and 1984. At Site M2R, located on the same bank but downstream from the Bonnybrook Sewage Treatment Plant, dissolved phosphorus concentrations were very dissimilar among the years. During 1981, values decreased to a minimum at the end of May. Thereafter dissolved phosphorus increased, peaking in July, August, October and November. During 1982, the concentration of dissolved phosphorus was higher. Values fluctuated less but again increased following a June minimum. October values in both 1981 and 1982 were equal to or higher than May values (Figure 5). During 1984, dissolved phosphorus was lower at Site 2, i.e., less than 0.25 $mg \cdot L^{-1}$.

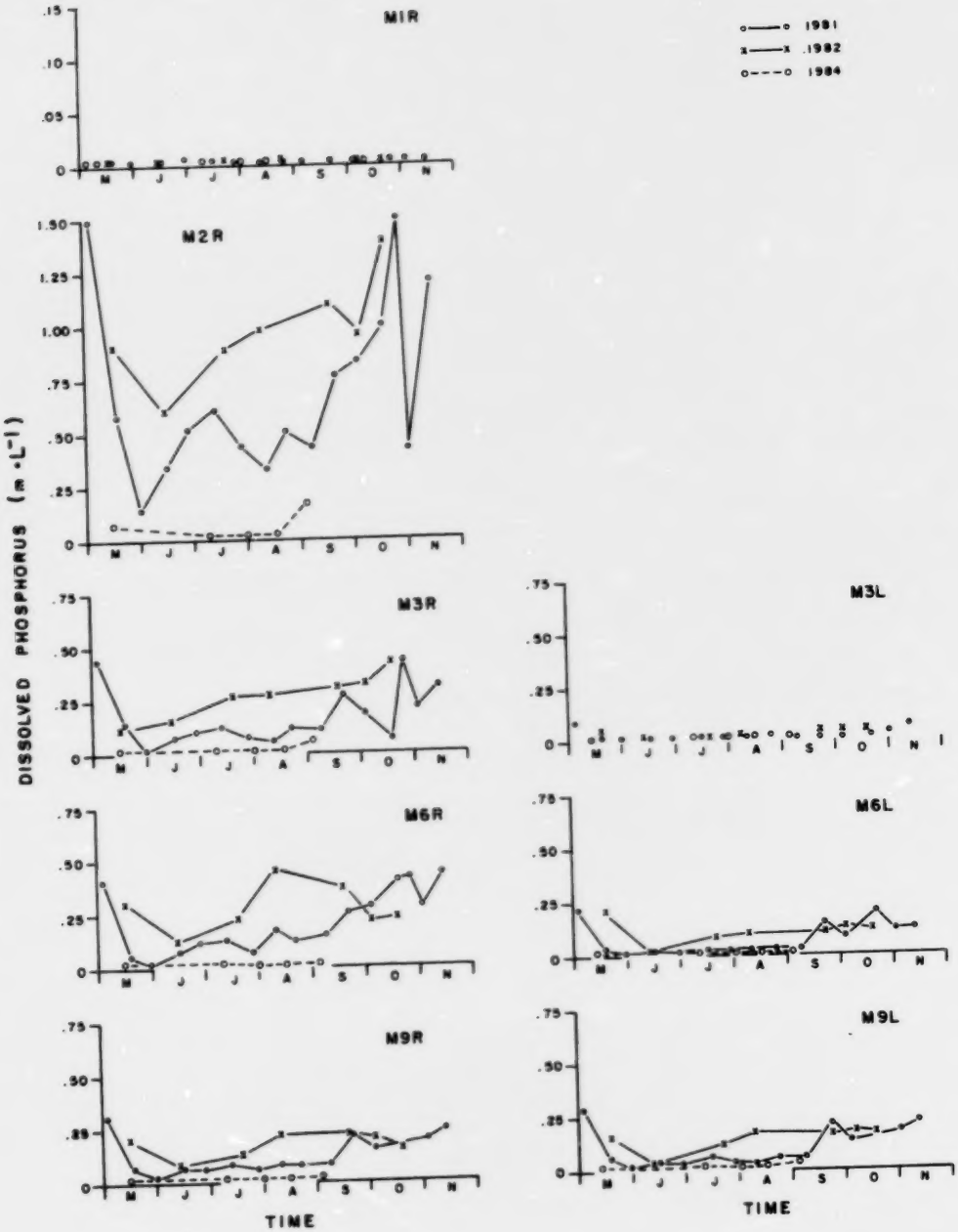

Figure 5 FLUCTUATIONS IN DISSOLVED PHOSPHORUS CONCENTRATIONS IN THE BOW RIVER DOWNSTREAM OF CALGARY (1981, 1982 and 1984)

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Values also decreased to a minimum in July and August but increased after August presumably due to the onset of macrophyte senescence.

Dissolved phosphorus concentrations were lower at Site M3R than at M2R (Figure 5). Temporal patterns were, however, similar to those found upstream at M2R. After the installation of phosphorus removal, dissolved phosphorus concentrations remained near the detection limit except during early September, 1984. Site M3L exhibited little seasonal fluctuation and remained very low in dissolved phosphorus. Low concentrations and the lack of temporal fluctuation were indicative of few macrophytes and the lack of complete mixing at Site M3 (Figure 5). Dissolved phosphorus concentrations were also higher during 1982 than 1981 and 1984 at Sites M6R and M6L. Temporal patterns were similar to those found at Site M2R, however, the concentrations of dissolved phosphorus were lower at Site M6. Again values were lower at the left bank due to lack of complete lateral mixing.

At Sites M9R and M9L, dissolved phosphorus exhibited the same temporal patterns and the concentrations of dissolved phosphorus were similar between right and left banks. Therefore, it would appear that complete mixing had occurred by Site 9 located 30 kilometers downstream of Site M1 (Figure 5). Both Site 6 and Site 9 were found to have dissolved phosphorus concentrations of less than 0.1 $mg \cdot L^{-1}$ following the installation of phosphorus removal at Calgary.

3.6 Temporal Fluctuations of Epilithic Chlorophyll *a* Downstream of Calgary

The temporal fluctuations of epilithic chlorophyll *a* are presented in Figure 6 for 1981, 1982 and 1984. At Site M1R, upstream of the zone of enrichment, standing crops were lowest in 1981 followed by 1982 and 1984, respectively. In 1981, epilithic chlorophyll *a* peaked during November. In 1982, standing crops fluctuated and peaked during July and again in September and October. During 1984, epilithic standing crop continually decreased after a spring (May) peak. Unfortunately, samples were not collected during the fall period; however, fall peaks have been shown to occur throughout the Bow River Basin (Charlton, Hamilton and Cross 1986).

At Site M2R, downstream of the Bonnybrook Sewage Treatment Plant, standing crops were higher than upstream. The temporal fluctuation of standing crops were quite similar during 1981 and 1982 but dissimilar during 1984. In May 1984, epilithic algal standing crops were similar to those detected at Site M1R; however, high values were sustained until July. Thereafter, chlorophyll *a* decreased to a minimum in August and increased again in September. At Site M3R, the pattern in 1984 was similar to that found at Site M1R in 1984 except for a mid-August peak. During 1981, M3R underwent three successive peaks of chlorophyll *a*. Site M3L supported less epilithic chlorophyll *a* and a fall peak was evident only in 1982.

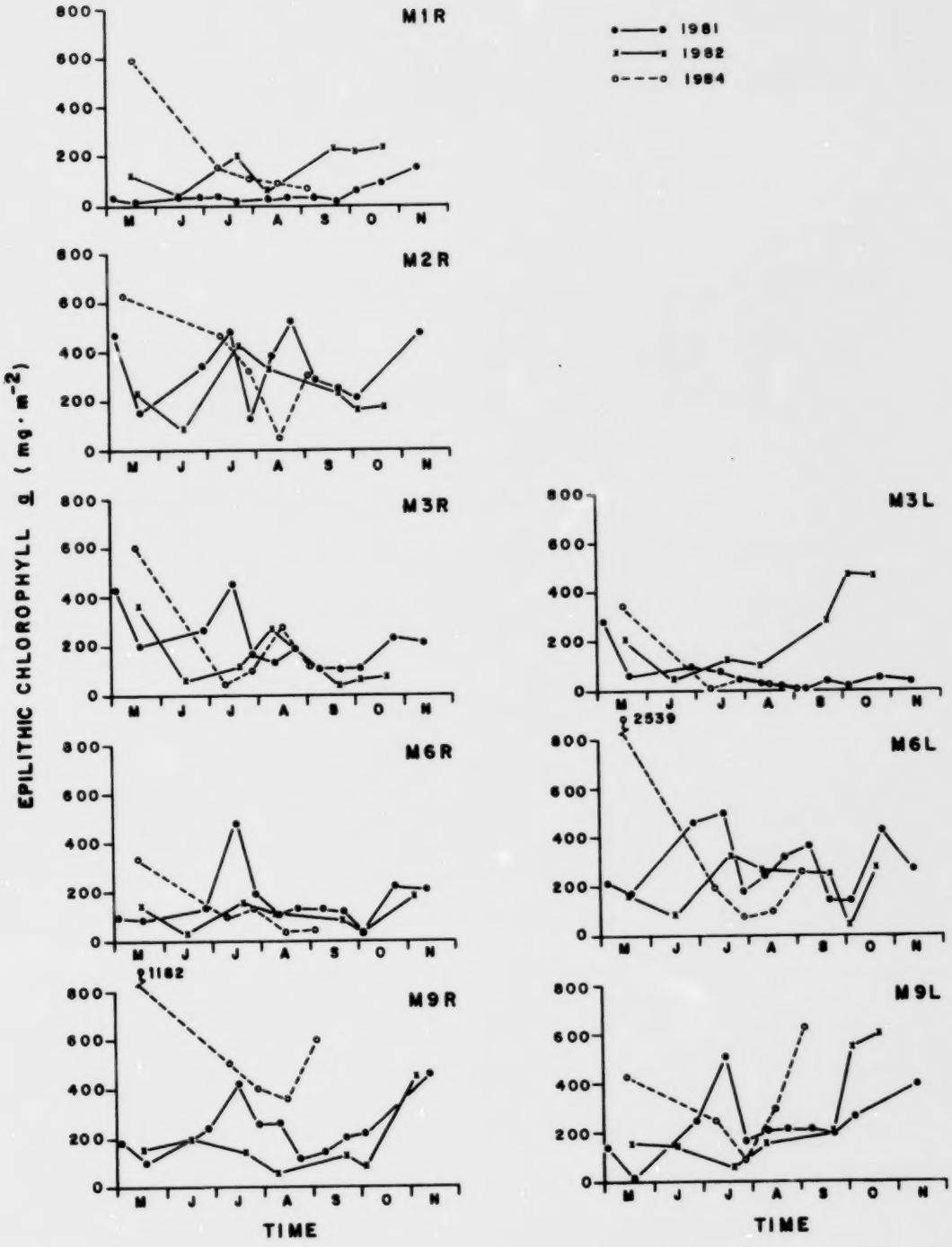

Figure 6 FLUCTUATIONS IN EPILITHIC CHLOROPHYLL a CONCENTRATIONS IN THE BOW RIVER DOWNSTREAM OF CALGARY (1981, 1982, and 1984)

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At Site M6, downstream of the Fish Creek Sewage Treatment Plant effluent input, temporal fluctuations of chlorophyll *a* and a fall peak were evident only in 1982.

At Site M6, downstream of the Fish Creek Sewage Treatment Plant effluent input, temporal fluctuations of chlorophyll *a* were similar to those found at Site M3R. The actual standing crops, however, were lower. Site M6L supported higher standing crops than M6R and underwent a series of successive peaks in July, September and October of 1981 and 1982. Although epilithic standing crops were much higher at M6L (1984), this site underwent temporal fluctuations similar to those found at M2R in 1984.

Similar temporal fluctuations were found at Site M9 for both right and left bank in 1981 and 1982. During 1984 epilithic chlorophyll *a* was higher at M9R, however, both sites underwent similar temporal fluctuations.

3.7 Peak Macrophyte Standing Crops Downstream of Calgary

The temporal variation of peak macrophyte standing crops for 1981 through 1985 are presented in Figure 7. During 1981, peak values were lower at all sites than any year thereafter. That particular year represented a high flow year when the peak macrophyte standing crop was probably limited by physical factors.

The peak macrophyte standing crop increased in 1982 and reached a maximum at most sites in 1983. Only Sites M5 and M9 supported lower peak standing crops in 1983 than in 1982.

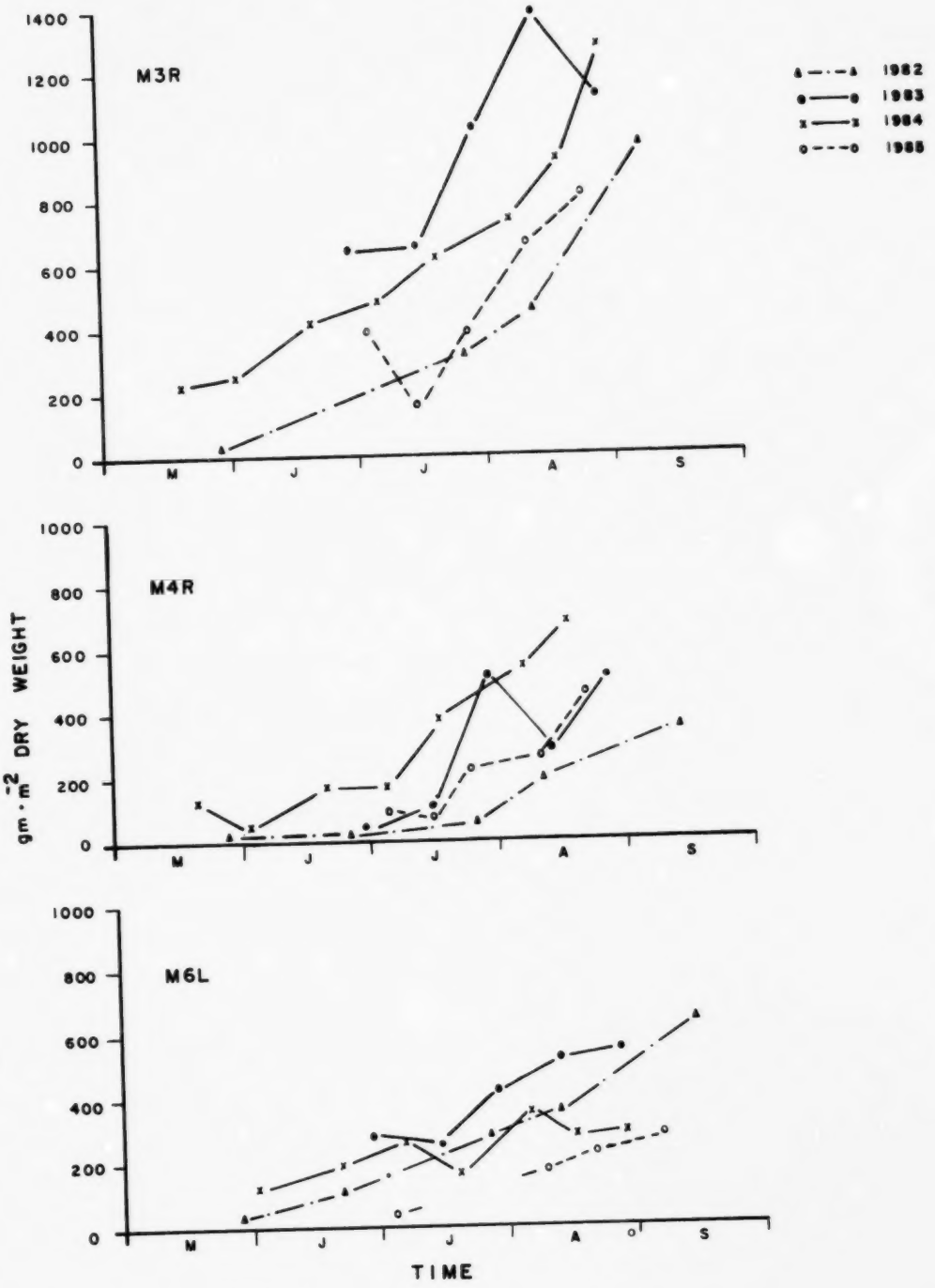

FIGURE 7 TEMPORAL VARIATION OF MEAN TRANSECT STANDING CROP ($gm \cdot m^{-2}$ dry weight)

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After 1983, a low flow year, peak macrophyte biomass decreased downstream of Calgary. One exception was found at M2 immediately downstream of the Bonnybrook Sewage Treatment Plant outlet. Values were slightly higher in 1985 than 1984 (Figure 7).

3.8 The Temporal Variation of Macrophyte Standing Crops

Figure 8 presents the temporal variation of mean transect macrophyte standing crops for Sites M3R, M4R and M6L. At each successive downstream site, macrophytes accumulated biomass throughout the open water period. Mid-August depression of standing crops occurred at M3R and M4R in 1983 and at M6L in 1984. This decrease during late August was indicative of the onset of senescence.

The June spate of 1983 at M3R, all years at M4R and 1983 at M6L may have suppressed the initial accumulation of macrophyte tissue. Each river location, however, was found to exhibit a high degree of annual variation. At M3R mean macrophyte biomass was highest in 1983 followed by 1984, 1985 and 1982 respectively. At M4R, standing crops were highest in 1984 followed by 1983, 1985 and 1982, respectively. Annual variations were less pronounced at M6L, with 1983 and 1985 having the highest and lowest standing crops, respectively.

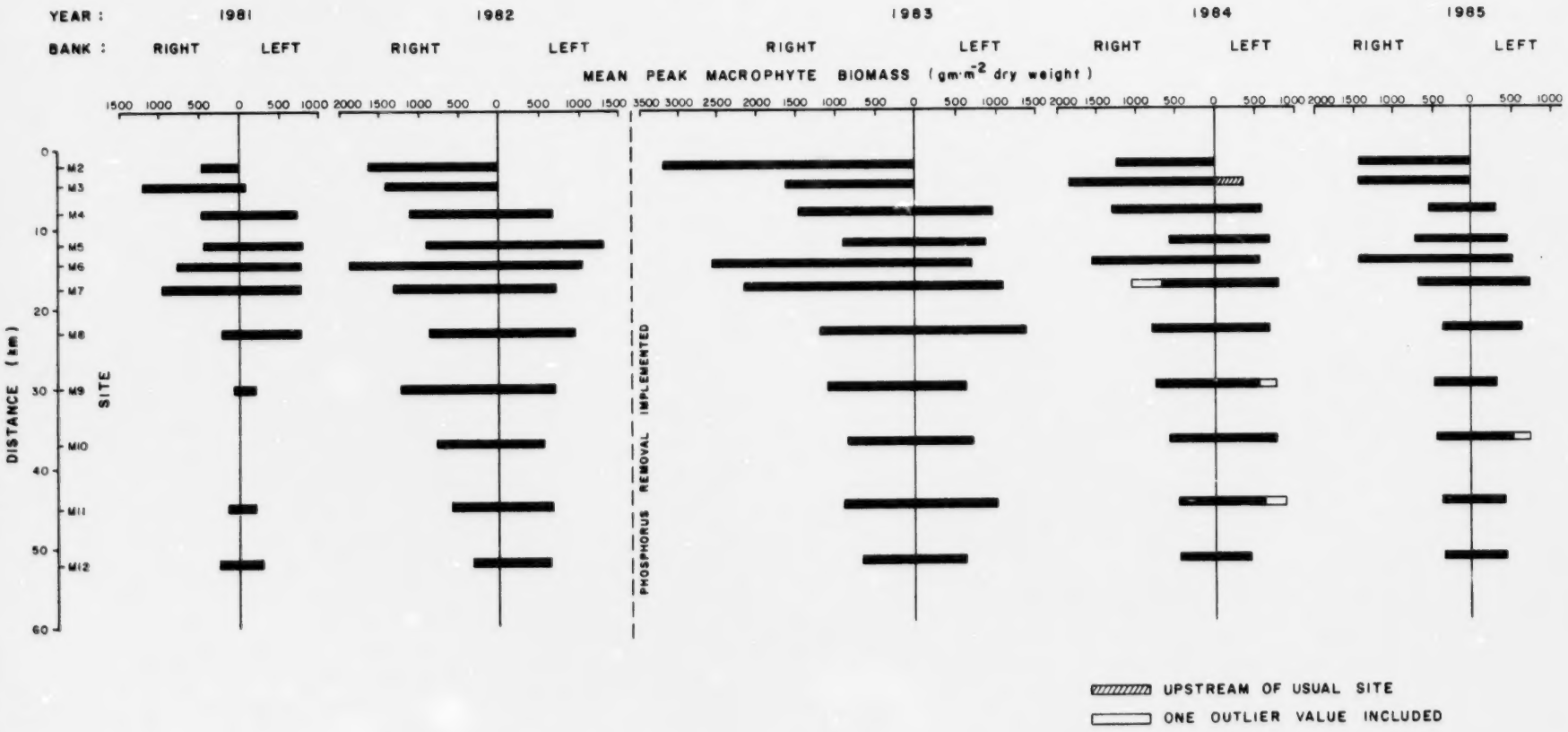

Figure 8 PEAK MACROPHYTE STANDING CROPS AT SUCCESSIVE SITES DOWNSTREAM OF CALGARY

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4.0 DISCUSSION

The Bow River, as with other running water (lotic) systems, is subjected to a myriad of factors which influence its ecology annually and seasonally. Unlike the undisturbed aquatic systems, however, the Bow River has undergone a reduction in the concentration of dissolved phosphorus since early 1983. The installation of phosphorus removal at the Bonnybrook and Fish Creek sewage treatment plants reduced mean dissolved phosphorus concentrations from 0.169 $mg \cdot L^{-1}$ to 0.022 $mg \cdot L^{-1}$ at Site 2 (downstream of Calgary).

It would appear that phosphorus reductions have contributed to lower phytoplankton standing crops in the Bow River. However, epilithic algal standing crops have not been reduced by the installation of phosphorus removal.

Epilithic algae are extremely opportunistic and have evolved to survive despite low phosphorus concentrations. Not only are some species capable of fixing elemental nitrogen, they also accumulate phosphorus to facilitate growth (luxury uptake) during periods of nutrient limitation. Moreover, epilithic algae grow attached to the river substrate and have been shown to take up nutrients from their substrate.

Epilithic algae are extremely important to the overall stability of aquatic ecosystems. They provide food and shelter for the aquatic

invertebrates which in turn are integral components of the Bow River food chain. Epilithic algae rarely form nuisance growths due to their microscopic morphological characteristics. One exception has been recorded for the Bow River Cladophora species. This particular alga flourishes in shallow, rapidly flowing river reaches and is common to both disturbed and undisturbed lotic systems. Cladophora species are a minor concern compared to the larger macrophytes which flourish downstream of the sewage treatment plants.

Macrophytes are the large, non-vascular aquatic plants which present the greatest concern to Bow River users. These plants interfere with boating, swimming and fishing and may clog water intakes. Macrophytes are perennial but flourish during the open water period. They accumulate photosynthetic tissue throughout the summer, resulting in greater problems for water users as the summer progresses. Macrophytes impede the flow of water, which increases the rate of sedimentation in backwaters and slow-flowing river regions. They modify the stream bed in such a way as to make it a more optimal habitat. They are, however, sensitive to high river velocities, nutrient concentrations and factors which abrade their photosynthetic tissue.

In the Bow River, macrophytes did not respond immediately to the installation of phosphorus removal. It would appear that they continued to flourish during the open water period due to a number of factors. Firstly, macrophytes can absorb nutrients via their rhizomes located in the river bottom. Secondly, they store nutrients in their rhizomes over the winter to supplement the following year's growth. Thirdly, macrophytes are capable of luxury uptake of phosphorus. Fourthly, Bow River discharge maxima have decreased during each successive year since 1981, hence the macrophyte communities have not been extensively scoured. Due to this combination of factors, the macrophyte standing crop in the Bow River immediately downstream of Calgary has not disappeared. The visual impact and the problems macrophytes present to water users remain.

Quantitative results presented in this report have documented that macrophyte standing crops are decreasing in the Bow River. Macrophytes can be expected to continue to decrease as the sediment and water nutrient sink is depleted of the essential nutrient, phosphorus. More normal flows in the Bow River (in future years) may also affect the macrophyte standing crop.

5.0 CONCLUSIONS

The installation of phosphorus removal at the Bonnybrook and Fish Creek Sewage Treatment Plants has reduced dissolved phosphorus concentrations to less than 0.1 $mg \cdot L^{-1}$ in the Bow River. The removal of this nutrient, essential for aquatic plant growth, has not affected the standing crop of epilithic algae. The reduct' of this nutrient, however, has reduced the standing crops of phyto[illegible]ktonic algae and macrophytes downstream of Calgary. Moreover, the removal of phosphorus has resulted in lower nutrient concentrations at each successive downstream site. Phosphorus removal has not influenced the concentrations of total and faecal coliform bacteria. These variables frequently exceed the Alberta Surface Water Quality Objectives (Alberta Environment, 1977).

Finally, it would appear that water quality in the Bow River, with respect to nutrient concentrations and macrophyte standing crop, has improved, particularly since 1983. Although extremely difficult to compare temporally and horizontally, the nuisance growth of aquatic macrophytes can be expected to decrease as the nutrient sinks of the Bow River are slowly depleted.

6.0 REFERENCES

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7.0 APPENDIX

Range Table of Bow River

1980 - 1985

Range Table for Bow River 1980 - 1985

	Dissolved Oxygen $mg \cdot L^{-1}$	Conductance $\mu S \cdot cm^{-1}$	pH units	Total Alkalinity $meq \cdot L^{-1}$	Water Temp. °C	Chlorophyll a Phytoplankton $mg \cdot m^{-3}$	Chlorophyll a Epilithon $mg \cdot m^{-2}$	Ammonia $mg \cdot L^{-1}$	Nitrate/ Nitrite $mg \cdot L^{-1}$	Total Diss. Phosphorus $mg \cdot L^{-1}$	Total Phosphorus $mg \cdot L^{-1}$
Site 1											
BH2090/2105											
1980 n/x	0/	77/319	76/8.3	47/1.72	71/5.9	10/4.15	10/36.89	38/L0.1	48/0.041*	71/0.003*	86/0.006*
Range		254-367	7.1-8.5	1.23-2.24	0-16.0	0.5-11.5	11-72	L0.1-L0.1	L0.01-0.16	L0.003-0.009	L0.003-0.02
1981 n/x	0/	45/315	45/8.2	8/2.36	52/5.79	8/2.99	8/24.14	25/0.106*	21/0.052*	43/0.007*	45/0.024*
Range		264-355	8.0-8.4	2.0-2.53	0-17.0	0.4-8.6	8.0-50.16	L0.1-0.2	L.01-0.11	L.003-0.023	L0.003-0.02
1982 n/x	0/	3/287	3/8.2	0/	2/2.5	0/	0/	3/L0.1	3/0.07	3/0.003*	3/0.005
Range		246-321	8.1-8.4		0-5.0			L0.1-L0.1	0.03-0.12	L0.003-0.004	0.003-0.01
1983 n/x	14/11.5	15/215	16/8.1	16/1.90	16/7.55	15/1.47	15/78.55	15/L0.1	15/0.032	14/0.008*	14/0.01
Range	8.9-13.8	188-265	6.8-8.6	1.6-2.41	0.2-16.5	0.15-2.9	14.24-169	L0.1-L0.1	0.01-0.08	L0.003-0.037	0.01-0.05
1984 n/x	19/11.9	19/286	18/8.0	19/2.00	19/7.78	19/1.48	17/48.96	19/0.145*	20/0.026*	16/0.007*	18/0.009*
Range	9.2-14.6	220-335	7.2-8.9	1.59-2.39	0-18.0	0-4.38	8.66-123.3	L0.1-0.95	L0.01-0.10	L0.003-0.04	L0.003-0.04
1985 n/x	10/10.6	10/282	9/8.1	10/1.84	10/10.2	10/1.57	10/40.80	9/0.026*	9/0.024	9/0.004*	9/0.009
Range	7.5-13.5	236-329	7.7-8.4	1.65-2.02	3.1-18.2	0.40-3.94	0-83.57	L0.01-0.10	0.003-0.055	L0.003-0.006	0.004-0.02
Site 2											
BH2160											
1980 n/x	0/	57/358	46/8.0	7/1.80	68/9.7	7/3.19	7/269.36	36/0.653*	46/0.769	72/0.194	76/0.233
Range		304-441	7.6-8.7	1.6-2.22	0-21.0	0.93-9.85	122.8-438.7	L0.1-2.8	0.28-1.4	0.038-0.37	0.07-0.43
1981 n/x	0/	65/363	65/7.9	38/2.52	57/8.22	1/8.02	37/229.53	25/0.262*	55/1.005	65/0.164	35/0.27
Range		287-442	7.3-8.7	2.30-2.90	0-21.0		11.8-488.5	L0.1-1.5	0.17-2.4	0.019-0.33	0.05-0.58
1982 n/x	0/	2/382	2/7.8	0/	3/9.5	0/	0/	4/0.15*	2/1.8	4/0.15	2/0.34
Range		353-410	7.7-7.8		0-14.2			L0.1-0.2	1.4-2.1	0.14-0.16	0.33-0.34
1983 n/x	16/12.5	15/257	16/7.8	16/2.02	16/8.90	15/6.84	15/290.0	15/0.832*	15/.731	14/0.026	15/0.07
Range	8.0-15.4	211-330	6.2-8.7	1.69-2.6	1.5-19.0	2.45-11.64	14.8-678.7	L0.1-2.4	0.31-1.3	0.01-0.064	0.02-0.35
1984 n/x	19/12.4	19/348	18/7.7	19/2.14	19/8.19	19/5.12	17/244.18	19/0.700*	18/0.863	19/0.020*	19/0.057
Range	8.3-15.1	263-436	6.3-8.7	1.72-2.70	0-17.6	1.65-12.92	53.1-701.8	L0.1-1.6	0.38-1.40	L0.003-0.07	0.006-0.22
1985 n/x	10/11.2	9/328	9/7.9	10/1.98	10/10.2	10/5.16	10/190.78	9/0.452	9/1.16	9/0.021	9/0.053
Range	8.9-15.1	285-390	7.7-8.3	1.75-2.24	2.8-17.4	1.39-13.61	39.3-441.3	0.05-1.310	0.580-1.81	0.014-0.030	0.032-0.08

n = # of samples
x = mean
* = mean includes values at the detection limit

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Range Table for Bow River 1980 - 1985

	Dissolved Oxygen mg L^{-1}	Conductance uS cm^{-1}	ph units	Total Alkalinity meq L^{-1}	Water Temp. °C	Chlorophyll a Phytoplankton mg m^{-3}	Chlorophyll a Epilithon mg m^{-2}	Ammonia mg L^{-1}	Nitrate/ Nitrite mg L^{-1}	Total Diss. Phosphorus mg L^{-1}	Total Phosphorus mg L^{-1}
Site 5											
BM2215											
1980 n/x	0/	59/365	59/8.1	9/2.04	80/9.54	9/5.53	9/329.65	29/0.448*	27/0.780	74/0.142	78/0.178
Range		303-481	7.6-8.7	1.72-2.83	0-21.0	2.4-8.5	190-739	L0.1-2.4	0.26-1.2	0.003-0.25	0.091-0.42
1981 n/x	0/	20/369	20/8.0	7/2.30	25/8.7	7/7.04	7/211.9	17/0.451*	20/0.828	10/0.138	10/0.172
Range		295-446	7.6-8.5	2.1-2.45	0-17.0	1.7-18.0	63.0-525.9	L0.1-1.0	0.28-1.5	0.03-0.29	0.053-0.32
1982 n/x	0/	2/374	2/7.9	0/	2/2.5	0/	0/	0/	2/0.84	2/0.16	2/0.20
Range		341-406	7.7-8.0		0-5.0				0.49-1.2	0.10-0.22	0.14-0.25
1983 n/x	15/11.6	14/252	16/7.7	16/2.07	16/8.64	15/5.03	14/236.8	15/0.312*	15/0.828	15/0.020	15/0.04
Range	9.9-14.2	230-300	6.2-8.7	1.67-3.07	0.1-19.0	2.48-9.61	11.3-743.4	L0.1-0.77	0.37-1.2	0.005-0.05	0.01-0.11
1984 n/x	19/10.8	19/348	18/7.7	19/2.16	19/8.16	19/6.36	15/352.2	19/0.394*	19/0.932	18/0.025*	19/0.004
Range	9.1-14.7	251-473	6.8-8.4	1.75-2.75	0-18.2	0.52-19.8	97.6-752.9	L0.1-1.44	0.07-1.5	L0.003-0.08	0.01-0.120
1985 n/x	10/10.5	9/342	9/7.9	10/2.00	10/10.3	10/5.99	9/256.23	9/0.132	9/1.02	9/0.021	9/0.046
Range	8.4-12.6	273-399	7.0-8.3	1.71-2.17	2.2-17.6	1.58-11.14	136-382	0.02-0.33	0.70-1.51	0.015-0.029	0.025-0.07
Site 6											
BM2230/2240											
1980 n/x	0/	33/363	33/8.5	11/2.00	38/11.0	11/3.43	11/106.58	32/0.305*	33/0.606	27/0.103	33/0.146
Range		311-516	7.6-9.3	1.5-2.29	0-22	0.43-9.31	2.08-388.6	L0.1-2.4	0.07-1.1	0.011-0.27	0.059-0.33
1981 n/x	0/	24/371	24/8.4	3/2.25	26/10.7	3/5.50	3/216.10	21/0.406*	24/0.786	24/0.108	24/0.166
Range		294-496	7.6-8.7	2.1-2.6	0-18.1	4.63-5.81	15.7-362	L0.1-1.0	0.13-1.6	0.005-0.29	0.024-0.47
1982 n/x	0/	4/317	4/8.5	0/	2/0	0/	0/	4/0.3*	4/0.69	4/0.113	4/0.203
Range		262-412	7.7-9.2		0-0			L0.1-0.6	0.22-1.5	0.055-0.23	0.073-0.38
1983 n/x	16/11.5	15/273	16/8.0	16/2.04	16/10.12	15/3.44	15/236.3	15/0.12*	15/0.650	15/0.020	15/0.03
Range	7.6-20.0	240-330	7.4-8.7	1.45-2.8	0.8-22.8	1.33-9.5	21.3-508.9	L0.1-0.3	0.16-1.1	0.006-0.045	0.01-0.08
1984 n/x	17/11.8	17/368	16/8.0	17/2.22	17/9.53	17/4.90	16/140.38	17/0.136*	17/0.786	17/0.015*	17/0.040
Range	8.8-14.2	233-475	6.9-9.2	1.46-2.88	0.1-20.9	0.54-14.49	28.0-655	L0.1-0.96	0.04-1.3	L0.003-0.07	0.01-0.08
1985 n/x	10/11.4	9/317	9/8.2	10/1.95	10/12.1	10/5.16	10/192.3	9/0.038*	9/778	9/0.018	9/0.053
Range	7.8-15.7	264-390	8.0-8.7	1.55-2.22	2.2-19.7	1.65-8.74	60.0-395.4	L0.01-0.110	0.24-1.43	0.007-0.028	0.016-0.10

n = # of samples
x = mean
* = mean includes values at the detection limit

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Range Table for Bow River 1980 - 1985

	Dissolved Oxygen $mg \cdot L^{-1}$	Conductance $\mu S \cdot cm^{-1}$	pH units	Total Alkalinity $meq \cdot L^{-1}$	Water Temp. °C	Chlorophyll a Phytoplankton $mg \cdot m^{-3}$	Chlorophyll a Epilithon $mg \cdot m^{-2}$	Ammonia $mg \cdot L^{-1}$	Nitrate/ Nitrite $mg \cdot L^{-1}$	Total Diss. Phosphorus $mg \cdot L^{-1}$	Total Phosphorus $mg \cdot L^{-1}$
Site 13 BN2245											
1980 n/x	0/	31/360	31/8.4	12/1.86	35/9.0	12/5.29	12/51.86	31/0.305*	31/0.524*	26/0.080	30/0.136
Range		256-507	7.6-9.1	1.2-2.7	0-22	1.1-29.1	4.3-162.9	L0.1-1.1	L.01-1.1	0.009-0.21	0.017-0.38
1981 n/x	0/	22/376.8	22/8.3	9/2.31	29/9.6	9/23.38	9/87.61	20/0.341*	22/0.761*	22/0.107	21/0.159
Range		292-512	7.6-9.0	1.8-2.8	0-21.1	2.6-83.5	14.7-229.6	L0.1-0.9	L0.01-1.6	0.005-0.26	0.02-0.3
1982 n/x	0/	3/317	3/8.2	0/	2/4.5	0/	0/	2/0.3*	3/0.73	3/0.119	3/0.243
Range		221-405	7.6-9.3		3.0-6.0			L0.1-0.5	0.04-1.5	0.016-0.27	0.039-0.[illegible]
1983 n/x	14/11.9	15/277.2	16/8.2	16/1.95	16/10.64	15/5.24	15/126.59	15/0.1*	15/0.422*	15/0.013	15/0.03
Range	9.0-16.0	221-331	7.4-2.41	1.16-9.3	0-25.5	1.8-16.6	24.1-325.3	L0.1-0.3	L0.01-1.2	0.007-0.030	0.01-0.06
1984 n/x	19/12.2	18/340	17/8.2	19/2.04	19/10.45	19/4.06	14/97.81	19/0.106*	19/0.672	18/0.011*	19/0.026
Range	9.3-15.4	211-465	6.9-10.2	1.14-2.97	0.0-22.2	0.01-11.1	13.23-34.3	L0.1-1.1	L0.01-1.7	L0.003-0.032	0.005-0.057
1985 n/x	10/10.9	9/326	9/8.3	8/1.88	10/13.4	10/6.62	8/48.78	9/0.102	9/0.499*	9/0.014	9/0.048
Range	8.6-12.9	264-420	7.9-9.2	1.28-2.33	2.5-23.7	1.65-21.1	6.38-105.4	0.010-0.48	L0.003-1.1	0.007-0.03	0.014-0.124
Site 7 BN2270											
1980 n/x	0/	32/389.8	32/8.3	10/1.96	34/9.4	10/2.08	10/76.30	31/0.282*	32/0.536*	27/0.072	28/0.132
Range		316-512	7.6-9.0	1.48-2.22	0-22.0	0.64-3.26	18.8-135.8	L0.1-1.4	L0.01-1.4	0.006-0.20	0.012-0.46
1981 n/x	0/	22/386.6	22/8.4	8/2.32	27/9.9	8/8.30	8/65.11	19/0.317*	22/0.680*	22/0.086	22/0.117
Range		311-542	7.6-8.1	2.0-2.96	0-22.0	0.3-41.5	22.3-160.0	L0.1-1.0	L0.01-1.6	0.004-0.23	0.021-0.25
1982 n/x	0/	3/346	3/8.1	0/	2/5.0	0/	0/	2/0.2*	3/0.79	3/0.106	3/0.202
Range		286-414	7.6-9.0		5.0-5.0			L0.1-0.3	L0.01-1.5	0.007-0.25	0.027-0.32
1983 n/x	14/11.5	15/304	16/8.0	16/2.08	16/10.08	15/5.67	15/108.13	15/0.12*	15/0.362*	15/0.014	14/0.04
Range	7.8-16.5	250-392	7.5-9.1	1.45-2.95	0.2-19.6	1.0-25.3	41.4-209	L0.1-0.4	L0.01-1.06	0.007-0.028	0.02-0.13
1984 n/x	18/11.3	18/388	17/8.0	18/2.14	18/11.2	18/2.65	17/107.6	18/0.143*	18/0.577*	18/0.011*	18/0.032
Range	9.0-13.8	291-483	6.6-9.1	0.152-2.79	0.1-24.8	0.0-6.53	30.0-484.9	L0.1-1.2	L0.01-1.7	L0.003-0.027	0.006-0.110
1985 n/x	10/10.4	9/366.1	9/8.0	8/1.91	10/11.7	10/5.68	9/103.98	9/0.039*	9/254*	9/0.012	9/0.051
Range	7.1-13.1	296-470	7.6-8.4	1.61-2.36	1.4-19.6	1.55-7.96	58.6-164.0	L0.01-0.09	L0.003-1.3	0.007-0.018	0.019-0.142

n = # of samples
x = mean
* = mean includes values at the detection limit

Alberta
ENVIRONMENT
Pollution Control Division
Water Quality Control Branch